

METHOD FOR THE PRODUCTION OF A PLURALITY OF
OPTOELECTRONIC SEMICONDUCTOR CHIPS AND OPTOELECTRONIC
5 SEMICONDUCTOR CHIP

This patent application claims the priority of German Patent Application 10335080.2, the disclosure content of which is hereby incorporated by reference.

10 The invention relates to a method for the production of a plurality of optoelectronic semiconductor chips each having a plurality of structural elements with respectively at least one semiconductor layer. In this
15 case, semiconductor layers of the structural elements are grown by means of selective epitaxy. The invention additionally relates to an optoelectronic semiconductor chip produced according to this method.

20 Such an optoelectronic semiconductor chip and a corresponding method for the production thereof are described in DE 199 11 717 A1, for example. Said chip has a plurality of radiation coupling-out elements comprising e.g. an epitaxially grown semiconductor
25 layer sequence with an active layer that generates electromagnetic radiation. This component thereby has improved coupling-out of radiation.

30 Each of the radiation coupling-out elements has a ring contact on a top surface, the ring contacts being interconnected by electrically conductive paths. This is a relatively complicated way of making electrically conductive contact with the radiation coupling-out elements, and requires the radiation out-coupling
35 elements to have a certain minimum size.

The present invention is based on the object of providing an improved method for the production of

optoelectronic semiconductor chips of the type mentioned in the introduction. A further object of the present invention is to provide a semiconductor chip produced according to such a method which has improved 5 properties compared with conventional semiconductor chips.

These objects are achieved by means of a production method having the features of claim 1 and, 10 respectively, by means of an optoelectronic component having the features of claim 14. Claims 2 to 13 relate to advantageous embodiments of the method.

According to the invention, the method for the 15 production of a plurality of optoelectronic semiconductor chips of the type mentioned in the introduction comprises at least the following method steps:

provision of a chip composite base having a substrate 20 and a growth surface;

formation of a mask material layer on the growth surface, with a multiplicity of windows, most of which have an average extent of less than or equal to 1 μm , a mask material being chosen in such a way that a 25 semiconductor material of the semiconductor layer that is to be grown in a later method step essentially cannot grow on said mask material or can grow in a substantially worse manner in comparison with the growth surface;

30 essentially simultaneous growth of semiconductor layers on regions of the growth surface that lie within the windows; and

singulation of the chip composite base with applied material to form semiconductor chips.

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In this context, propagation is to be understood as the length of a window projected onto a straight line, the

straight line running in a principal extending plane of the mask material layer. The average propagation is accordingly the propagation of a window averaged over all directions.

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With smaller windows in the mask material layer, it is possible to produce smaller structure elements in a larger area density. This may lead to improved properties of the component, such as, for instance, 10 improved coupling-out of electromagnetic radiation generated in the component.

Preferably, the chip composite base has at least one semiconductor layer grown epitaxially onto the 15 substrate. In this case, the growth surface is a surface on that side of the epitaxially grown semiconductor layer which is remote from the substrate.

In one advantageous embodiment of the method, the chip 20 composite base has a semiconductor layer sequence grown epitaxially onto the substrate, said semiconductor layer sequence comprising an active zone that emits electromagnetic radiation. The growth surface is correspondingly a surface on that side of the 25 semiconductor layer sequence which is remote from the substrate. The semiconductor layers of the structural elements that are subsequently applied to the growth surface form a patterning which, by way of example, fulfills the purpose of improved coupling-out of the 30 electromagnetic radiation generated in the chip composite base.

As an alternative or in addition, the structural elements respectively have an epitaxially grown 35 semiconductor layer sequence with an active zone that emits electromagnetic radiation.

Preferred materials for the mask material layer have SiO_2 , Si_xN_y or Al_2O_3 .

After the growth of the semiconductor layers of the
5 structural elements, a layer made of electrically
conductive contact material that is transmissive to an
electromagnetic radiation emitted by the active zone is
preferably applied to said semiconductor layers, so
that semiconductor layers of a plurality of structural
10 elements are electrically conductively connected to one
another by the contact material. It is thereby possible
to form electrical contact structures in a simple
manner which additionally absorb a small proportion of
electromagnetic radiation generated in the component.

15 In one embodiment of the method, the mask material
layer is expediently at least partly removed after the
growth of the semiconductor layers.

20 In a further embodiment of the method, after the growth
of the semiconductor layer sequences, advantageously as
an alternative or in addition to the removal of mask
material, a planarization layer is applied over the
growth surface. This may lead to improved coupling-out
25 of light particularly when a material whose refractive
index is lower than that of adjoining semiconductor
layers is chosen for said planarization layer.

30 The planarization layer preferably has a material
having dielectric properties.

In the growth of the semiconductor layers of the
structural elements, the growth conditions are
preferably set and alternatively or additionally varied
35 during growth in such a way that the semiconductor
layers are formed with a form that is advantageous for

the coupling-out of electromagnetic radiation, for example an at least appropriately lenslike form.

5 The mask material layer and the semiconductor layers are particularly preferably grown by means of metal organic vapor phase epitaxy (MOVPE).

10 The optoelectronic semiconductor chip is characterized by the fact that it is produced according to the method according to the invention or an embodiment thereof.

15 Further advantages, preferred embodiments and developments of the method and, respectively, of the optoelectronic semiconductor chip emerge from the exemplary embodiments explained below in conjunction with Figures 1A to 3, in which:

20 Figures 1A to 1D show a schematic plan view of a detail from a growth surface during different stages of an exemplary embodiment of the method;

25 Figure 2 shows a schematic sectional view of a detail from a first embodiment of the optoelectronic component; and

Figure 3 shows a schematic sectional view of a detail from a second embodiment of the optoelectronic component.

30 In the embodiments and figures, identical or identically acting constituent parts are respectively provided with the same reference symbols. The constituent parts illustrated and also the size relationships among the constituent parts are not to be
35 regarded as true to scale. Rather, some details of the figures are illustrated with an exaggerated size in order to afford a better understanding.

Figures 1A to 1D show in chronological succession in each case a detail from a growth surface 3 during the growth of a mask material layer 11 made from a mask material 1. In this case, the mask material layer 11 is grown in situ in a non-closed layer in such a way that a plurality of statistically distributed windows arise. "In situ" means that the growth takes place in the same epitaxy reactor as the growth of semiconductor layers of the component. As an alternative, it is also possible to grow a closed mask material layer in which windows are subsequently formed by means of photolithography and etching.

15 The growth surface 3 may be for example an area of a substrate made from n-GaAs; the mask material 1 is composed e.g. of Si_xN_y .

The growth of the mask material 1 begins at isolated points on the growth surface 3 at which crystallites of mask material 1 form. The crystallites of mask material 1 accrete laterally in the further course of events (see Figures 1B to 1D), in which case the growth conditions may be set for example in such a way that 25 two-dimensional growth is predominant, that is to say that the crystallites of mask material 1 grow predominantly in a plane parallel to the growth surface, and only to a lesser degree perpendicular thereto. As an alternative, through corresponding 30 setting of the growth conditions, it is also possible to achieve predominantly three-dimensional growth of the crystallites, that is to say a growth in which the growth rate is of similar magnitude or of an identical order of magnitude in all possible growth directions.

35 Growth conditions are in this case to be understood as externally settable, controllable or changeable

parameters such as e.g. pressure, temperature, material flow and growth duration in the epitaxy reactor. The precise values for such parameters for obtaining a specific growth characteristic can vary greatly and 5 depend for example on the partitioning and the geometrical dimensions of the epitaxy reactor or on the material to be grown.

With the setting of the growth conditions, it is 10 possible in the growth of the mask material layer not just to vary the form or the size of the windows, rather it is also advantageously possible, by way of example, to set the surface density with which the windows are produced on the growth surface.

15 The production of a non-closed Si_xN_y layer is effected for example in an MOVPE reactor by admitting SiH_4 and NH_3 at a suitable reactor temperature, which may typically lie in a range of between 500 and 1100°C. 20 However, the reactor temperature may also lie above or below this range. Such methods are described for instance in Hageman, P.R. et al., phys. stat. sol. (a) 188, No. 2 (2001), 659-662, the content of which is in this respect hereby incorporated by reference. As an 25 alternative, the Si source used may also be tetraethyl-silicon ($\text{Si}(\text{C}_2\text{H}_5)_4$) or a similar Si-containing compound which is suitable for epitaxy.

In the growth stage shown in Figure 1D, the mask 30 material layer 11 has been fully formed. It has a plurality of statistically distributed windows 2 having varying forms and opening areas. The deposition conditions are chosen such that most of the windows have an average extent of less than 1 μm . By means of a 35 small extent of the windows it is possible to produce more and smaller structural elements and e.g. to

achieve improved coupling-out of radiation from the component structures.

Subsequently, for example semiconductor layer sequences 5 are deposited selectively on regions of the growth surface 3 that lie within said windows 2 (see Figure 2 or 3). Said semiconductor layer sequences may be based for instance on phosphide compound semiconductors and preferably have materials $In_nGa_mAl_{1-n-m}P$, where $0 \leq n \leq 1$, 10 $0 \leq m \leq 1$ and $n+m \leq 1$. In this case, these materials may have one or more dopants and additional constituents which essentially do not change the physical properties of the material.

15 A semiconductor layer sequence 8 forms a structural element 12. In the sense of the invention, it is also possible in this case for semiconductor layers of a plurality of structural elements to overlap or for a plurality of structural elements to have at least one 20 common semiconductor layer. This is the case for example if semiconductor layer sequences 8 grow laterally over the mask material layer to an extent such that semiconductor layers of adjacent structural elements 12 partly or wholly accrete. In such cases a 25 boundary between two adjacent structural elements runs along a line along which semiconductor material situated on the mask material layer has a minimum thickness.

30 In Figure 2, the semiconductor layer sequence 8 forming the structural element 12 has an active zone that emits electromagnetic radiation when current is applied. However, a structural element 12 may also have no active zone and e.g. be formed from only one 35 semiconductor layer having a lenslike form.

The active zone may have a conventional pn junction, for example for a light emitting diode. Such structures are known to the person skilled in the art and are therefore not explained in any greater detail at this 5 conjuncture.

By virtue of the fact that the windows have opening areas of different magnitudes, different material compositions result for the layers of the semiconductor 10 layer sequences 8 that are deposited therein. In the case of structures emitting electromagnetic radiation, different emission spectra consequently result, so that with radiation-emitting components of this type it is possible overall to achieve a broader emission spectrum 15 than with conventional components.

Figure 2 shows a schematic sectional view of a detail from an optoelectronic component produced by the method. The chip composite base 5 comprises a substrate 20 4 and a semiconductor layer or semiconductor layer sequence 6 which is grown epitaxially on said substrate and whose side remote from the substrate 4 forms the growth surface 3. A mask material layer 11 is grown on the growth surface 3 and, in the component detail 25 shown, has a window into which a semiconductor layer sequence 8 is selectively deposited.

The maximum thickness of the mask material layer 11 may be e.g. only a few nm and is less than the height of 30 the semiconductor layer sequence 8. As a result, semiconductor layers of the semiconductor layer sequence 8, above a height that is greater than the thickness of the mask material layer 11 surrounding them, are also partly grown over the mask material 35 layer 11 by lateral growth.

The growth conditions for the growth of the

semiconductor layer sequence 8 are e.g. chosen or varied during growth in such a way that the semiconductor layer sequence 8 is formed with a lenslike form. As an alternative, said form may also be 5 like a truncated cone or polyhedral.

In this context, the term "growth conditions" is to be understood in a manner similar to the growth of mask material 1 explained above. In this case, how precisely 10 the setting of specific values for parameters such as pressure, temperature, material flow and growth duration affects the growth of semiconductor materials depends not only on the type of semiconductor material to be grown and the type of epitaxy installation but 15 also greatly on the type of mask material 1.

In the embodiment illustrated in Figure 2, the semiconductor layer grown last covers all the remaining semiconductor layers of the semiconductor layer 20 sequence 8. This makes it possible to apply a layer made from electrically conductive contact material 7 for example flat over the entire growth surface 3 or on the semiconductor layer sequence 8 and the mask material 1 without different semiconductor layers of 25 the semiconductor layer sequence 8 being electrically short-circuited. Suitable contact material 7 is for example indium tin oxide (ITO) or else a metal layer a few atomic layers thick, for example made from platinum, which due to its small thickness is 30 transmissive to a radiation emitted by the active zone of the semiconductor layer sequence 8.

A contact material with ITO may additionally have a thin metal layer of this type which is deposited before 35 the ITO. It is thereby possible to improve the electrical conductivity of the contact between contact material 7 and semiconductor layer sequence 8.

In order that an electrically conductive contact forms between the contact material 7 and the semiconductor layer sequence 8, after the application of the contact 5 material 7 the component generally has to be subjected to heat treatment at a suitable temperature for a sufficiently long time. These measures are known to the person skilled in the art and are therefore not explained in any greater detail.

10 A bonding pad via which the semiconductor layer sequence can be contact-connected from one side e.g. by means of a bonding wire (not shown) may be applied to the contact material 7 before or after the heat 15 treatment.

If the substrate 4 is provided with a contact material and electrically conductively connected on the rear side, that is to say on the side remote from the growth 20 surface, then a voltage can be applied via the bonding pad and the rear side contact directly to the still united components and their functionality can be tested (direct probing).

25 In the case of the component of the detail shown in Figure 2, the semiconductor layer sequence 6 arranged on the substrate 4 may alternatively or additionally also have an active zone that emits electromagnetic radiation. When a voltage is applied to the component, 30 the current is restricted through the mask material layer 11 to a region of the windows 2, so that a light generating region is essentially restricted to a part of the active zone of the semiconductor layer sequence 6 which lies below a window 2.

35 Figure 3 shows the detail from a second exemplary embodiment of the component. In contrast to the

embodiment explained with reference to Figure 2, the production method in this example comprises, after the application of the semiconductor layer sequence 8, removal of the mask material layer 11, which may be 5 effected by selective etching.

A planarization layer 10 is subsequently applied to the growth surface 3 and the semiconductor layer sequence 8, which planarization layer may be composed e.g. of a 10 dielectric whose refractive index is lower than that of materials of the semiconductor layer sequence 8.

In order that electrically conductive contact can be made with the semiconductor layer sequence 8, the 15 planarization layer 10 is then at least partly thinned or removed, so that the outermost layer of the semiconductor layer sequence 8 is uncovered. Subsequently, analogously to the embodiment explained with reference to Figure 2, electrically conductive 20 contact material 7 is applied thereto and heat treatment is effected.

Subsequently, the chip composite base 5 with the applied material can be singulated to form a plurality 25 of optoelectronic semiconductor chips. Each of these semiconductor chips comprises a plurality of structural elements 12.

The scope of protection of the invention is not 30 restricted by the description of the invention on the basis of the embodiments. By way of example, the windows in the mask material layer can be made so small that quasi one-dimensional semiconductor component structures are grown in them. The invention encompasses 35 any new feature and also any combination of features, which in particular comprises any combination of features in the patent claims even if this combination

is not explicitly specified in the claims.